Hydraulics of Closed Conduit Spillways

Part XVII:

The Two-Way Drop Inlet with a Semicylindrical Bottom

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Preface

This publication, the 17th part of a group of publications dealing with the hydraulics of closed conduit spillways, reports tests on the two-way drop inlet with a semicylindrical bottom. Parts I throught XI were published as technical papers under the major title "Hydraulics of Closed Conduit Spillways" by the St. Anthony Falls Hydraulic Laboratory (SAFHL), University of Minnesota, Minneapolis, Minn. Parts XII through XVI were published under the same major title by the Science and Education Administration (formerly Agricultural Research Service). The earlier publications are:

Part I: Theory and Its Application, F. W. Blaisdell. SAFHL Tech. Paper No. 12, Ser. B, 22 pp., illus., January 1952 (rev. February 1958). Gives theory, symbols, and bibliography.

Parts II through VII: Results of Tests on Several Forms of the Spillway, F. W. Blaisdell. SAFHL Tech. Paper No. 18, Ser. B, 50 pp., illus., March 1958. Parts II through VI describe the hydraulic performance and present discharge coefficients for five forms of the closed conduit spillway; Part VII discusses vortices and their effect on the spillway capacity.

Part VIII: Miscellaneous Laboratory Tests; Part IX: Field Tests, F. W. Blaisdell. SAFHL Tech. Paper No. 19, Ser. B, 54 pp., illus., March 1958. Reports tests on models of specific field structures and on field structures themselves.

Part X: The Hood Inlet, F. W. Blaisdell and C. A. Donnelly. SAFHL Tech. Paper No. 20, Ser. B, 41 pp., illus., April 1958. Reports the development of the hood inlet.

Part XI: Tests Using Air, F. W. Blaisdell and G. G. Hebaus. SAFHL Tech. Paper No. 44, Ser. B, 53 pp., illus., January 1966. Discusses the use of air for tests of closed conduit spillways.

Part XII: The Two-Way Drop Inlet with a Flat Bottom, C. A. Donnelly, G. G. Hebaus, and F. W. Blaisdell. ARS-NC-14, 66 pp., illus., September 1974. Reports tests on the two-way drop inlet for closed conduit spillways.

Part XIII: The Hood Drop Inlet, K. Yalamanchili and F. W. Blaisdell. ARS-NC-23, 78 pp., illus., August 1975. Reports tests on the hood drop inlet for closed conduit spillways.

Part XIV: Antivortex Walls for Drop Inlets; Part XV: Low-Stage Inlet for the Two-Way Drop Inlet, C. A. Donnelly and F. W. Blaisdell. ARS-NC-33, 37 pp., illus., January 1976. Part XIV reports the results of tests on antivortex walls for hood drop inlets, rectangular drop inlets, square drop inlets, and circular drop inlets. The findings are used to verify the vortex envelope of Humphreys, Sigurdsson, and Owen. Part XV reports the results of tests on low-stage inlets for two-way drop inlets, gives conclusions regarding the size and location of the low-stage inlets, and presents an equation for determining the capacity of the low-stage inlet.

Part XVI: Elbows and Transitions for the Two-Way Drop Inlet, C. L. Anderson. AAT-NC-1, 44 pp., illus., February 1979. Reports tests on double-circular and elliptical elbows for use between the two-way drop inlet and the crown of the barrel. Tests on transitions to change the crown cross section from semisquare to semicircular are also reported for the semicylindrical bottom drop inlet.

The study reported here of two-way drop inlets with semicylindrical bottoms was conducted by the staff of the St. Anthony Falls Hydraulic Laboratory Conservation Structures Investigations Unit, Science and Education Administration, U.S. Department of Agriculture, Minneapolis, at the St. Anthony Falls Hydraulic Laboratory, University of Minnesota, Minneapolis. C. A. Donnelly conducted the water experiments. G. G. Hebaus designed the two-way drop inlet models for the air tests. K. Yalamanchili completed the air tests, analyzed the data, and wrote the first draft of this report. The study was supervised by F. W. Blaisdell, who wrote the final draft.

Summary

This report presents the results of experiments on two-way drop inlets with semicylindrical bottoms for closed conduit spillways. The two-way drop inlet is a rectangular drop inlet having a width equal to the barrel diameter, a bottom semicircular in cross section, and a flat, horizontal antivortex plate supported above the drop inlet crest by extensions of the drop inlet endwalls. Two types of barrel entrances, referenced as A and B, were tested. In the type A entrance, the horizontal bottom of the drop inlet extended into the barrel beyond the downstream endwall where a vertical elbow changed the slope from horizontal to that of the barrel. In the type B entrance, the bottom of the drop inlet had the same slope as the barrel.

Spillway performance of the type A entrance is described for several drop inlet heights, drop inlet lengths, and antivortex plate heights. For both types of entrances effects of the midheight piezometer location, drop inlet length, antivortex plate height, and barrel slope on the crest loss, barrel entrance loss, and pressure coefficients for two-way drop inlets with semicylindrical bottoms are presented. Equations for computing the barrel entrance loss coefficients and the pressure coefficients on the barrel crown near the barrel entrance are developed and their precision is discussed. A method for computing the entrance loss coefficients is described. A summary of recommendations presents criteria for determining the drop inlet dimensions for the type A entrance and lists the equations for computing the energy loss coefficients—crest loss, barrel entrance loss, and total entrance loss coefficients—and pressure coefficients.

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Hydraulics of Closed Conduit Spillways

Part XVII: The Two-Way Drop Inlet with a Semicylindrical Bottom

Kesavarao Yalamanchili and Fred W. Blaisdell[1]

Introduction

The two-way drop inlet for a closed conduit spillway is a rectangular drop inlet having a width equal to the diameter of the spillway barrel. Water enters the drop inlet over its two longer sides. Horizontal, upward extensions of the two shorter sides (endwalls) of the drop inlet support trash racks at their outer ends and a flat, horizontal antivortex plate located above the drop inlet crest.

The two-way drop inlet is widely used by the Soil Conservation Service (SCS) as a principal spillway entrance for PL 566 watershed protection and flood prevention dams. A comprehensive experimental study of the two-way drop inlet with a horizontal, flat bottom has been completed and is reported in Part XII.[2]

To reduce the potential for collection of debris at the barrel entrance, SCS proposed that the drop inlet have a semicylindrical bottom instead of a flat bottom. Because the semicylindrical bottom has the same diameter as the barrel, the corners at the junction between the drop inlet and the barrel are eliminated, thereby providing a continuous surface at the barrel entrance below the barrel midheight. This eliminates the recessed corners at the flat bottom drop inlet barrel entrance—corners that might catch debris.

The semicylindrical bottom two-way drop inlet has been tested with types A and B square-edged barrel entrances. For the type A entrance shown in figure XVII-1(a), the two-way drop inlet has a horizontal, semicylindrical bottom. The barrel is also horizontal for about 1.5 barrel diameters (1.5**D**±) beyond the downstream endwall of the drop inlet. A vertical miter elbow then changes the slope from horizontal to the slope of the rest of the barrel. For the type B entrance shown in figure XVII-1(b), the two-way drop inlet has a semicylindrical bottom with a longitudinal bottom slope identical to that of the barrel.

The results of tests on semicylindrical-bottom two-way drop inlets having type A and type B barrel entrances are reported herein.

The minimum drop inlet dimensions that give satisfactory spillway performance were determined only for the type A entrance. These minimum dimensions are compared with those determined from the performance tests on the two-way drop inlet with a flat bottom reported in Part XII.

The location of the drop inlet midheight piezometer affects the magnitudes of the crest loss and barrel entrance loss coefficients, so this effect is discussed. The crest loss coefficients for two-way drop inlets with semicylindrical bottoms are compared with the experimental and equation XII-9 results for two-way drop inlets with flat bottoms. Equations are developed for computing the barrel entrance loss coefficients and the barrel crown pressure coefficients **D**/2 downstream from the barrel entrance. The precision of these empirical equations is discussed. A method is described for

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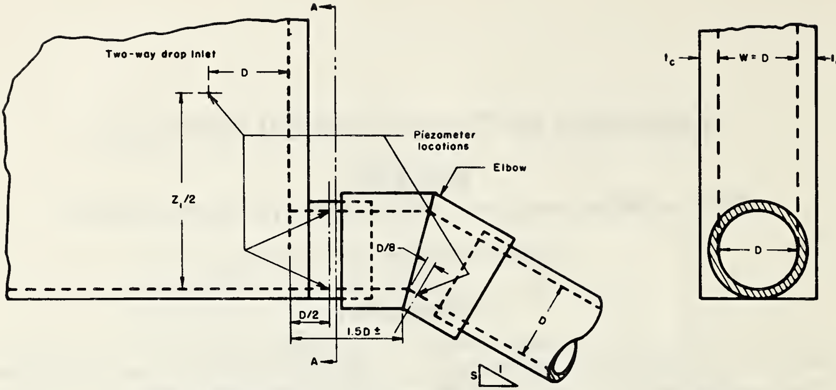
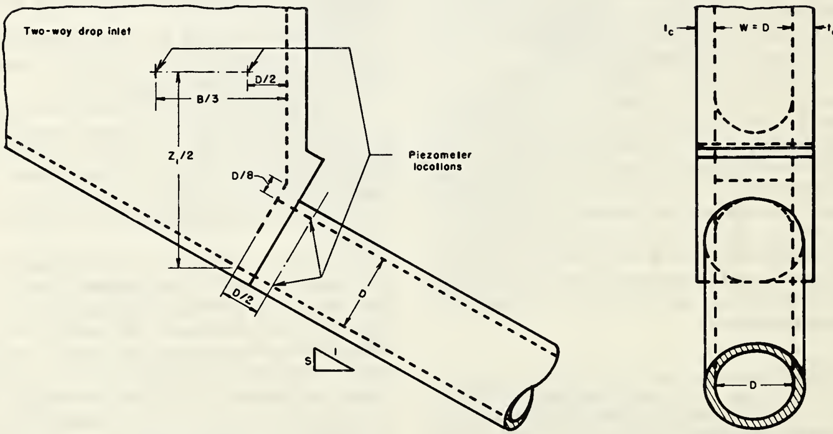
[2] The Roman numerals in references to parts, equations, figures, and tables refer to a particular Part of this series cited in the Preface.



SIDE ELEVATION

SECTION A-A

(a) Type A entrance



SIDE ELEVATION

DOWNSTREAM END

(b) Type B entrance

Figure XVII-1.—Barrel entrances for two-way drop inlets with semicylindrical bottoms.

computing the total entrance loss coefficient for two-way drop inlets with semicylindrical bottoms. The recommendations are summarized.

Experimental Program

Part XII presents the information needed to design two-way drop inlets with flat bottoms. The additional information needed to design two-way drop inlets with semicylindrical bottoms is the effect of the semicylindrical bottom and the barrel entrance on the spillway performance and on the entrance loss and pressure coefficients. This information was obtained by conducting a limited number of water and air tests on two-way drop inlets with semicylindrical bottoms.

Table XVII-1 summarizes the experimental program. Details not presented in table XVII-1 are described in the following paragraphs.

TABLE XVII–1.—
Summary of experimental program

Barrel entrance	Type A		Type B
Drop inlet floor	Horizontal		Sloping
Test fluid	Water		Air
Flow range	Weir, slug, full-pipe	Weir, slug	Full-pipe
Drop inlet height, Z_1/D	5.0	2.0 3.0 4.0 5.0	5.0
Drop inlet length, **B**/**D**	1.5 2.0 3.0 5.0	1.5 2.0 3.0 5.0	1.5 2.0 3.0 5.0
Antivortex plate height, Z_p/D	.2 .3 .4 .5 .6 .7 .8	.8	.8
Barrel slope, **S**, percent	20.0	20.0	0.0 2.5 5.0 10.0 20.0 30.0

The experimental program included 21 water series covering weir, slug and full-pipe flows, each series consisting of 20 to 24 test runs; 21 water series covering only weir and slug flows, each series consisting of 4 to 19 test runs; and 24 air series covering only full-pipe flows, each series consisting of 7 test runs.

The barrel inside diameter **D** was 2.25 inches for the water tests and 3 inches for the air tests.

The drop inlet width **W** was equal to the barrel diameter for all tests.

The drop inlet crest thickness t_c was not a variable in this study. However, different crest thicknesses were used for the two types of barrel entrances: 0.222**D** for type A and 0.083**D** for type B. The outside edge of the crest was square. The inside edge of the crest had a radius of one-half the crest thickness.

Antivortex plate overhangs L_o were 4**D** for the type A entrance and 2**D** for the type B entrance.

The drop inlet height Z_1 was measured from the drop inlet crest to its floor at the barrel entrance. The antivortex plate height Z_p was measured from the drop inlet crest to the bottom of the antivortex plate.

Pressures in the drop inlet were measured on one sidewall at the midheight of the drop inlet. However, as shown in figure XVII-1, the distance between the piezometer and the drop inlet downstream endwall was different for the two types of entrances: 1**D** for the type A entance, and **D**/2 and **B**/3 for the type B entrance.

Pressures in the barrel were measured on the crown and invert **D**/2 from the entrance for all tests. Also, for the type A entrance the pressure was measured on the miter bend invert about **D**/8 downstream from the bend.

Test Apparatus, Test Procedure, and Analytical Methods

The test apparatus, test procedure, and analytical methods used in this study are described in Part X for the water tests and in Part XI for the air tests.

TABLE XVII-2.—*Summary of water test results for the type A entrance*

$D = 2.25$ in., $t_c = 0.222D$, $L_o = 4D$, $S = 0.20$

Series	$\frac{Z_1}{D}$	$\frac{B}{D}$	$\frac{Z_p}{D}$	K_c	K_t Observed	K_t Computed	K_t Error Percent	K_e Observed	K_e Computed	K_e Error Percent	h_n/h_{vp} @ D/2 Crown	h_n/h_{vp} @ D/2 Invert	h_n/h_{vp} @ D/8 Elbow invert	Notes[1]
W-533	5	5.0	0.8	3.07	0.48	0.57	18.8	0.56	0.61	8.9	−1.06	−0.26	−0.66	a
W-534	5	5.0	.7	.64	.56	.57	1.8	.58	.61	5.2	−1.08	− .27	− .67	a
W-535	5	5.0	.6	1.20	.57	.57	0.0	.59	.61	3.4	−1.10	− .27	− .67	a
W-536	5	5.0	.5	1.14	.57	.57	0.0	.60	.62	3.3	−1.10	− .27	− .67	a
W-537	5	5.0	.4	2.13	.55	.57	3.6	.60	.64	6.7	−1.12	− .26	− .64	a
W-538	5	5.0	.3	4.01	.54	.57	5.6	.64	.69	7.8	−1.10	− .25	− .63	a b
W-539	5	5.0	.2	—	—	—	—	—	—	—	—	—	—	c d
W-521	5	3.0	.8	.27	.65	.62	−4.6	.66	.67	1.5	−1.10	− .21	− .61	a
W-515	5	3.0	.7	.25	.62	.62	0.0	.64	.68	6.3	−1.08	− .20	− .58	a
W-516	5	3.0	.6	.47	.60	.62	3.3	.63	.69	9.5	−1.08	− .21	− .58	a e
W-517	5	3.0	.5	.81	.60	.62	3.3	.66	.72	9.1	−1.09	− .21	− .57	a
W-518	5	3.0	.4	1.55	.60	.62	3.3	.71	.77	8.5	−1.12	− .21	− .57	a b
W-519	5	3.0	.3	3.42	.55	—	—	.78	—	—	−1.08	− .15	− .50	c f
W-520	5	3.0	.2	—	—	—	—	—	—	—	—	—	—	c d g
W-522	5	2.0	.8	.29	.71	.70	−1.4	.73	.80	9.6	−1.13	− .14	− .52	a
W-523	5	2.0	.7	.37	.70	.70	0.0	.74	.81	9.5	−1.12	− .13	− .50	a
W-524	5	2.0	.6	.59	.71	.70	−1.4	.78	.84	7.7	−1.15	− .14	− .52	a b
W-525	5	2.0	.5	.95	.71	.70	−1.4	.84	.89	6.0	−1.17	− .15	− .53	a b
W-526	5	2.0	.4	1.35	.70	—	—	.89	—	—	−1.18	− .16	− .54	c f
W-527	5	2.0	.3	—	—	—	—	—	—	—	—	—	—	c g
W-540	5	2.0	.8	—	—	—	—	—	—	—	—	—	—	a
W-541	5	2.0	.7	—	—	—	—	—	—	—	—	—	—	a
W-542	5	2.0	.6	—	—	—	—	—	—	—	—	—	—	a b h
W-543	5	2.0	.5	—	—	—	—	—	—	—	—	—	—	a h
W-544	5	2.0	.4	—	—	—	—	—	—	—	—	—	—	b i
W-545	5	2.0	.3	—	—	—	—	—	—	—	—	—	—	c d
W-528	5	1.5	.8	.38	.82	.81	−1.2	.93	.96	3.2	−1.20	− .05	− .49	a
W-529	5	1.5	.7	.49	.80	—	—	.93	—	—	−1.22	− .06	− .49	i
W-530	5	1.5	.6	.64	.75	—	—	.92	—	—	−1.21	− .08	− .50	c f
W-531	5	1.5	.5	.91	.74	—	—	.99	—	—	−1.22	− .09	− .51	c f
W-532	5	1.5	.4	—	—	—	—	—	—	—	—	—	—	c g
C-1	4	3.0	.8	—	—	—	—	—	—	—	—	—	—	a
C-2	4	2.0	.8	—	—	—	—	—	—	—	—	—	—	a
C-3	4	1.5	.8	—	—	—	—	—	—	—	—	—	—	a
C-7	3	5.0	.8	—	—	—	—	—	—	—	—	—	—	a j
C-6	3	3.0	.8	—	—	—	—	—	—	—	—	—	—	a
C-5	3	2.0	.8	—	—	—	—	—	—	—	—	—	—	a
C-4	3	1.5	.8	—	—	—	—	—	—	—	—	—	—	a
C-11	2	5.0	.8	—	—	—	—	—	—	—	—	—	—	c j
C-8	2	3.0	.8	—	—	—	—	—	—	—	—	—	—	i
C-9	2	2.0	.8	—	—	—	—	—	—	—	—	—	—	i
C-10	2	1.5	.8	—	—	—	—	—	—	—	—	—	—	c g

[1] Notes

a. Drop inlet dimensions meet the recommended criteria and the performance is satisfactory.
b. Headpool surface level fluctuates slightly.
c. Drop inlet dimensions do not meet the recommended criteria and the performance is poor.
d. Flow is controlled by the orifice formed by the drop inlet crest, the drop inlet endwalls, and the antivortex plate.
e. Harmless surface vortices are formed in the headpool.
f. Large headpool surface level fluctuations.
g. Drop inlet vibrates.
h. Flow is controlled by the height above the crest of the antivortex plate.
i. Drop inlet dimensions do not meet the recommended criteria but the performance is satisfactory.
j. Flow is controlled by the barrel entrance acting as an orifice.

TABLE XVII-3.—*Summary of air test results for the type B entrance*

$D = 3$ in., $Z_1 = 5D$, $t_c = 0.083D$, $Z_p = 0.8D$, $L_o = 2D$

Series[1]	B/D	S	$K_{c,1}$[2]	$K_{c,2}$[3]	K_c[4]	$K_{t,1}$[2]	$K_{t,2}$[3]	K_t Observed[4]	K_t Computed	K_t Error Percent	K_e Observed	K_e Computed	K_e Error Percent	h_n/h_{vp} @ D/2 Crown	h_n/h_{vp} @ D/2 Invert
A-1490	5.0	0.00	1.84	2.95	2.48	0.49	0.46	0.47	0.47	0.0	0.53	0.52	−1.9	−1.24	−0.31
A-1491	3.0	.00	1.46	1.63	1.46	.51	.50	.51	.52	2.0	.61	.60	−1.6	−1.25	− .26
A-1492	2.0	.00	1.26	1.26	1.26	.59	.59	.59	.60	1.7	.78	.76	−2.6	−1.28	− .19
A-1493	1.5	.00	1.20	1.20	1.20	.68	.68	.68	.71	4.4	1.00	.97	−3.0	−1.33	− .11
A-1494	5.0	.025	1.75	2.88	2.40	.47	.44	.45	.46	2.2	.51	.51	0.0	−1.24	− .31
A-1495	3.0	.025	1.50	1.67	1.50	.55	.54	.55	.51	−7.3	.65	.59	−9.2	−1.25	− .24
A-1496	2.0	.025	1.23	1.24	1.21	.58	.58	.58	.59	1.7	.77	.75	−2.6	−1.28	− .20
A-1497	1.5	.025	1.14	1.14	1.14	.67	.67	.67	.70	4.5	.98	.96	−2.0	−1.34	− .13
A-1498	5.0	.05	1.95	3.06	2.59	.47	.44	.45	.46	2.2	.52	.51	−1.9	−1.23	− .31
A-1499	3.0	.05	1.42	1.62	1.42	.52	.51	.52	.51	−1.9	.62	.59	−4.8	−1.24	− .25
A-1500	2.0	.05	1.25	1.28	1.19	.58	.58	.58	.58	0.0	.77	.74	−3.9	−1.29	− .20
A-1501	1.5	.05	1.15	1.15	1.15	.67	.67	.67	.68	1.5	.98	.94	−4.1	−1.33	− .12
A-1502	5.0	.10	2.03	3.17	2.68	.46	.43	.44	.45	2.3	.51	.50	−2.0	−1.22	− .30
A-1503	3.0	.10	1.50	1.72	1.50	.49	.47	.49	.49	0.0	.59	.58	−1.7	−1.23	− .26
A-1504	2.0	.10	1.27	1.29	1.23	.55	.55	.55	.57	3.6	.74	.72	−2.7	−1.26	− .20
A-1505	1.5	.10	1.25	1.25	1.25	.63	.63	.63	.66	4.8	.97	.92	−5.2	−1.31	− .11
A-1506	5.0	.20	2.06	3.31	2.78	.44	.42	.43	.44	2.3	.49	.49	0.0	−1.20	− .29
A-1507	3.0	.20	1.44	1.64	1.44	.48	.46	.48	.47	−2.1	.57	.55	−3.5	−1.22	− .25
A-1508	2.0	.20	1.25	1.27	1.21	.53	.52	.55	.53	−3.6	.72	.68	−5.6	−1.26	− .22
A-1509	1.5	.20	1.22	1.22	1.22	.59	.59	.59	.64	3.4	.91	.87	−4.4	−1.31	− .16
A-1510	5.0	.30	2.25	3.42	2.92	.42	.39	.40	.42	5.0	.47	.47	0.0	−1.20	− .29
A-1511	3.0	.30	1.46	1.65	1.46	.46	.45	.46	.44	−4.3	.56	.53	−5.4	−1.22	− .26
A-1512	2.0	.30	1.22	1.24	1.18	.50	.50	.50	.49	−2.0	.69	.65	−5.8	−1.25	− .23
A-1513	1.5	.30	1.15	1.15	1.15	.55	.55	.55	.56	1.8	.86	.82	−4.7	−1.29	− .18

[1] Drop inlet dimensions used for these series meet the recommended criteria.

[2] These coefficients are based on the readings of the piezometer located at the midheight of the drop inlet and **B**/3 upstream from the downstream endwall.

[3] These coefficients are based on the readings of the piezometer located at the midheight of the drop inlet and **D**/2 upstream from the downstream endwall.

[4] These coefficients are comparable to those obtained in the study of two-way drop inlets with flat bottoms and represent the values when the midheight piezometer is 1**D** upstream from the downstream endwall. They are computed by linear interpolation or extrapolation using the coefficients described in footnotes 2 and 3. Because both piezometer locations for 1.5**D**-long drop inlets are **D**/2 upstream from the downstream endwall, the linear extrapolation method fails. Because the differences between the two coefficients decrease as the drop inlet length decreases and apparently are close to zero for 1.5**D**-long drop inlets, the observed value of the coefficient is used for the 1.5**D**-long drop inlets.

Test Results

Summaries of the test results are presented in table XVII-2 for the water tests and in table XVII-3 for the air tests.

In the tables, the prefix A- denotes tests using the air apparatus, the prefix W- denotes tests on 5**D**-high drop inlets, the prefix C- denotes tests on shorter drop inlets (4**D**, 3**D**, and 2**D** high), K_c is the crest loss coefficient, K_t is the barrel entrance loss coefficient, K_e is the total entrance loss coefficient, h_n/h_{vp} is the pressure coefficient, h_n is the local pressure head deviation from the friction gradeline, and h_{vp} is the velocity head in the barrel. The crest loss coefficients $K_{c,1}$ and $K_{c,2}$ and the barrel entrance loss coefficients $K_{t,1}$ and $K_{t,2}$ are described in the table XVII-3 footnotes.

For K_t and K_e, the observed values, the computed values using equations and rules developed from the data, and the percentage deviations (error) of the computed values from the observed values are given. Barrel pressure coefficients at points on the crown and invert **D**/2 downstream from the barrel entrance are listed in both tables and, for the type A entrance, on the invert **D**/8 downstream from the elbow miter. In table XVII-2, notes describe the performance. The energy loss and pressure coefficients could not be determined for series W-520, W-527, W-532, W-539 through W-545, and C-1 through C-11 because these series were tested with only part-full flows.

Spillway Performance

Performance tests were conducted for only type A entrances. Use of the water apparatus was necessary to test performance. The drop inlet dimensions and the antivortex plate heights tested are listed in table XVII-1. For all tests the antivortex plate overhang was 4**D** and the barrel slope was 20 percent.

The spillway performance was evaluated from headpool water level recorder traces and from notes based on visual observations made during the tests. Criteria for determining satisfactory drop inlet performance were smooth and positive priming of the spillway, absence of inlet vibrations, nonexistence of orifice flow control (See note d, table XVII-2), and lack of large headpool water level fluctuations. Slight fluctuations in the headpool water level and surface vortices that did not affect the drop inlet performance were considered to be harmless. Letters in the Notes column of table XVII-2 record the performance of each drop inlet. Letters a, b, e, h, or i indicate that the drop inlet performs satisfactorily. Letters c, d, f, g, or j indicate that the drop inlet does not perform satisfactorily.

The minimum height and minimum length of drop inlets that give satisfactory performance were determined from the test results of series W-533, W-521, W-522, W-540, W-528, and C-1 through C-11. These series were selected because a common antivortex plate height (0.8**D**) was used for these tests.

Drop inlets 5**D**, 4**D**, and 3**D** high performed satisfactorily at all lengths tested. Notes taken during the 3**D**-high, 5**D**-long tests (series C-7) state that orifice control existed at the barrel entrance, but this orifice flow did not affect the priming.

For 2**D**-high drop inlets, the test results indicate that the drop inlets 2**D** and 3**D** long perform satisfactorily, but the drop inlet 1.5**D** long vibrated, and orifice flow at the barrel entrance of the 5**D**-long drop inlet affected the headpool level. Therefore, the overall performance of the 2**D**-high drop inlets was considered poor.

The minimum height of the drop inlet that gave uniformly satisfactory performance is 3**D**. This result agrees with the minimum height criteria established from the tests of the two-way drop inlet with a flat bottom.

Drop inlets 1.5**D**, 2**D**, 3**D**, and 5**D** long performed satisfactorily for all heights $Z_1 \geqq 3D$. Because the shortest drop inlet tested performed satisfactorily, the minimum length of the drop inlet that gives satisfactory performance cannot be determined from these tests. Considering the physical similarities and the agreement of the performance test results between the two-way drop inlets having flat and semicylindrical bottoms, the authors suggest that the minimum length of the drop inlet that gives satisfactory performance be taken as 1.5**D**—the recommended minimum drop inlet length for the two-way drop inlet with a flat bottom.

The minimum antivortex plate height that gives satisfactory performance was determined from the test results of the W- series and series C-1 through C-7. The antivortex plate heights tested range from 0.2**D** to 0.8**D**. The antivortex plate must be high enough to eliminate the possibilities of orifice control at the crest (note d of table XVII-2), fluctuations in the headpool water level (note f), or vibrations in the drop inlet (note g). A comparison of the note a (satisfactory performance) entries in table XVII-2 with the antivortex plate height indicates that the minimum antivortex plate heights for 1.5**D**-, 2**D**-, 3**D**-, and 5**D**-long drop inlets are 0.8**D**, 0.5**D**, 0.4**D**, and 0.3**D** respectively. In table XVII-4 these results are compared with the recommended minimum antivortex plate heights for two-way drop inlets with a flat bottom. This comparison shows that there is good agreement between the semicylindrical and flat bottom test results.

An analysis of the performance test results indicates that two-way drop inlets having horizontal, semicylindrical bottoms perform the same, within the limits of precision of the tests, as drop inlets having flat bottoms. Therefore,

TABLE XVII-4.—
Minimum antivortex plate height

$\frac{B}{D}$	$(Z_p/D)_{minimum}$		
	Flat bottom (Table XII-2)		Semicylindrical bottom (Present tests)
	C = 3.1	C = 4.0	
1.5	0.85	0.72	0.8
2.0	.55	.47	.5
3.0	.42	.36	.4
5.0	.30	.25	.3

See Nomenclature for definition of **C**.

the authors recommend that the drop inlet proportions presented in figure XII-28 be used for designing two-way drop inlets with horizontal, semicylindrical bottoms.

Because no data were obtained on the performance of the type B entrance, no recommendation can be made regarding the dimensions that will assure satisfactory performance of the sloping, semicylindrical bottom drop inlets. The results of more recent model tests made on a drop inlet with a sloping upstream endwall,[3] which probably has an effect on the flow similar to that of the sloping bottom, indicate that the sloping-bottom type B entrance should, if use of it is contemplated, be model-tested to determine its performance characteristics.

Crest Loss Coefficients

The crest loss coefficient K_c multiplied by the velocity head in the drop inlet h_{vr} gives the energy loss that occurs between the headpool surface and the midheight of the drop inlet. The crest loss coefficient depends on the location of the drop inlet midheight piezometer, the drop inlet length **B**, the antivortex plate height Z_p, and the crest wall thickness t_c; and is independent of the discharge, the type of barrel entrance, and the barrel slope.

Part XII gives the equation

$$K_c = \left\langle 1 - 2\frac{t_c}{D} \right\rangle^2 + \frac{0.1}{(Z_p/D)^3} + 0.02\left(\frac{B}{D}\right)^{5/2} \quad \text{(XII-9)}$$

for computing the crest loss coefficients for two-way drop inlets with flat bottoms. (The quantity in the pointed brackets is zero for negative numbers.) Because the flat and the semicylindrical bottom two-way drop inlets are identical in geometric form above the midheight piezometer location, another equation for computing the crest loss coefficient for drop inlets having semicylindrical bottoms is not developed. Instead, to determine if equation XII-9 satisfactorily represents the semicylindrical bottom data, the semicylindrical bottom crest loss coefficients are compared with the flat bottom values computed using equation XII-9.

The piezometers were located on the drop inlet sidewall at the midheight of the drop inlet **1D** upstream from the downstream endwall for the water tests and for the drop inlets used to develop equation XII-9, and **D**/2 and **B**/3 upstream from the downstream endwall for the air tests. Because the pressure at the midheight of the drop inlet varies along the drop inlet length, the location of the midheight piezometer affects the crest loss coefficient. The effects of the location of the midheight piezometer, of the drop inlet length, and of the antivortex plate height on the crest loss coefficients are presented in the following sections.

Effect of Midheight Piezometer Location

The piezometer located at the midheight of the drop inlet was used to separate the energy losses caused by the drop inlet crest from those attributable to the barrel entrance. Because the pressure at the midheight of the drop inlet varies along its length, the location of the midheight piezometer affects the magnitude of both the crest loss and the barrel entrance loss coefficients. The total entrance loss coefficient, however, does not depend on the location of the midheight piezometer if the same location is used to determine both K_c and K_t; see Part XII, p. 39, CAUTION.

Figure XVII-2—a typical plot—shows the crest loss coefficient $K_{c,1}$ and $K_{c,2}$ obtained from the pressures measured at the midheight of the drop inlet **B**/3 (open symbols) and **D**/2 (symbols with a slash) upstream from the downstream endwall for several drop inlet lengths and barrel slopes. Note that the **D**/2 and **B**/3 piezometer locations coincide when $B/D = 1.5$. The data shown in figure XVII-2 and in table XVII-3 indicate that the effect of the midheight piezometer location on the crest loss coefficient is significant for the longer drop inlets, $B/D > 2$, and becomes insignificant when $B/D \leqq 2$.

Also, an examination of table XVII-3 shows that the differences between the crest loss coefficients $K_{c,1}$ and $K_{c,2}$ decrease from about 1.15 for 5**D**-long drop inlets, to about 0.19 for 3**D**-long drop inlets, and to about 0.02 for 2**D**-long drop inlets.

The crest loss coefficients K_c presented in table XVII-2 for the type A entrance and in Part

[3] Blaisdell, F. W., and Anderson, C. L. Hydraulic model investigation of Marsh Creek dam principal spillway in Contra Costa County, Calif. ARS-NC-35, 21 pp., illus., January 1976.

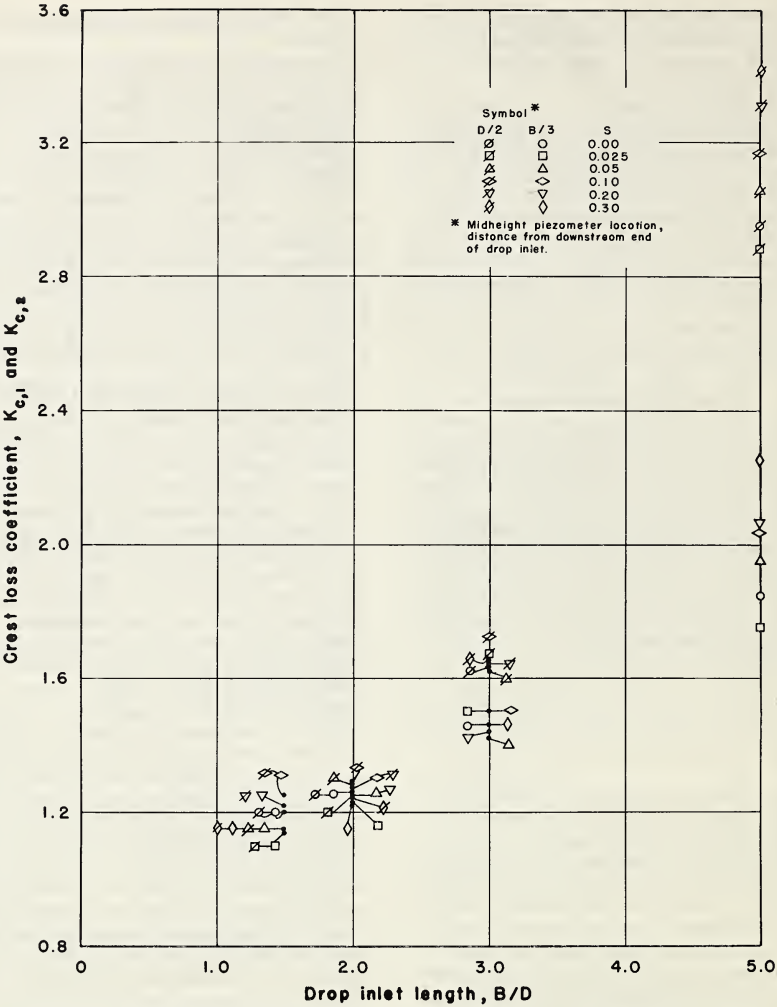


Figure XVII-2.—Effect of the piezometer location and drop inlet length on the crest loss coefficient.

XII for two-way drop inlets with flat bottoms are based on the pressures measured at the mid-height of the drop inlet 1D upstream from the downstream endwall. For the type B entrance the crest loss coefficients $K_{c,1}$ and $K_{c,2}$ are based on midheight piezometers located B/3 and D/2 upstream from the downstream endwall respectively.

To adjust the type B entrance data to the piezometer location used to develop equation

XII-9, the crest loss coefficients K_c for the type B entrance were computed for a piezometer located 1**D** upstream from the downstream endwall using the observed values of $K_{c,1}$ and $K_{c,2}$ and linear interpolation or extrapolation. These adjusted values of K_c are presented in table XVII-3 and will be used for all subsequent analyses.

Because the linear interpolation method fails when the distances to the location of both midheight piezometers are identical and are not at 1**D**, the crest loss coefficients for 1.5**D**-long drop inlets could not be computed by the linear interpolation method. As is evident from the above discussion of figure XVII-2 and table XVII-3, the effect of the midheight piezometer location on the crest loss coefficient is insignificant when $\mathbf{B} \leqq 2\mathbf{D}$. Therefore, $K_{c,1} = K_{c,2} \approx K_c$ for $\mathbf{B/D} = 1.5$, so the values of $K_{c,1} = K_{c,2}$ for $\mathbf{B/D} = 1.5$ have been inserted in the K_c column. These K_c values are used for all subsequent analyses.

Effect of Drop Inlet Length

The effect of the drop inlet length on the crest loss coefficient is shown in figure XVII-3. The crest loss coefficient increases as the drop inlet length increases. However, because the velocity head in the drop inlet decreases as the drop inlet length increases, the actual energy loss attributable to the crest also decreases as the drop inlet length increases. (See Part XII, p. 28, figure XII-4.)

Figure XVII-3(a) shows the crest loss coefficients obtained from tests on the type A two-way drop inlet semicylindrical-bottom entrance (represented by the circles), obtained from tests on the figure XII-1(a) two-way drop inlet flat-bottom entrance (squares), and computed from equation XII-9 (solid line). The trends of the crest loss coefficients shown in figure XVII-3(a) are the same for both entrances. No explanation is available for the high value of K_c for the 5**D**-long drop inlet (3.07). The equation values average 79 percent higher than the experimental results with maximum and minimum differences of +204 and −47 percent.[4] An attempt to explain part of this difference will be presented later in this section.

Figure XVII-3(b) shows the crest loss coefficients for the type B entrance (triangles), the figure XII-1(a) entrance (hexagons), and those computed from equation XII-9 (the solid line). The test results presented in figure XVII-3(b) indicate that the equation XII-9 values average 20 percent lower than the observed values with maximum and minimum differences of −18 and −21 percent.[4]

The precision of equation XII-9 is discussed in Part XII. The following statement is quoted from page 34 of Part XII:

> The equation XII-9 value of the crest loss coefficient is less than the observed value for the thinner crests and becomes greater than the test value for the thicker crests; the average percentage error in the crest loss coefficient gradually changes from −13 for $t_c/D = 0.1$ to +34 at $t_c/D = 0.33$ and remains constant for thicker crests.

From this statement, the average equation values are predicted to be 12 percent higher than the observed values for $t_c/D = 0.222$ (type A entrance) and 16 percent lower than the observed values for $t_c/D = 0.083$ (type B entrance). This partly explains why the equation XII-9 values are higher than the observed values in figure XVII-3(a) and lower than the observed values in figure XVII-3(b). Because the number of semicylindrical bottom data are limited, no attempt was made to improve the precision with which equation XII-9 represents the semicylindrical bottom data or to develop another equation for computing the crest loss coefficients.

Effect of Antivortex Plate Height

The effect of antivortex plate height on the crest loss coefficient for the four drop inlet lengths tested using the type A entrance is shown in figure XVII-4. The crest loss coefficient is large for low plate heights and decreases as the plate height increases. Figure XVII-4 also permits a comparison of the crest loss coefficients for the type A entrance (circles), the figure XII-1(a) entrance (squares), and those computed from equation XII-9 (the solid line). The agreement between the test results for both entrances is satisfactory. As predicted in the previous section, the coefficients computed from equation XII-9 are higher than the observed values.

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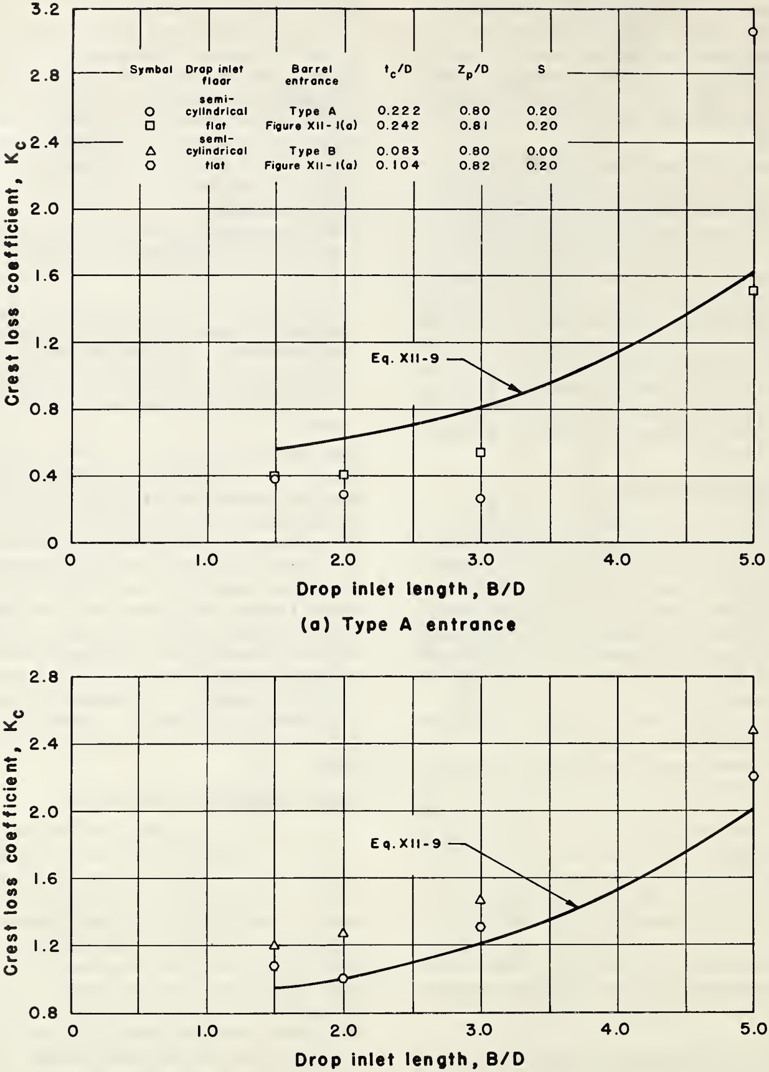
[4] To aid in comparing the precision of the semicylindrical bottom results with the flat bottom results presented in Part XII: The average error of equation XII-9 determined from the valid flat bottom tests is +22 percent with a maximum of +92 percent and a minimum of −41 percent.



(a) Type A entrance

(b) Type B entrance

Figure XVII-3.—Effect of drop inlet length on the crest loss coefficient.

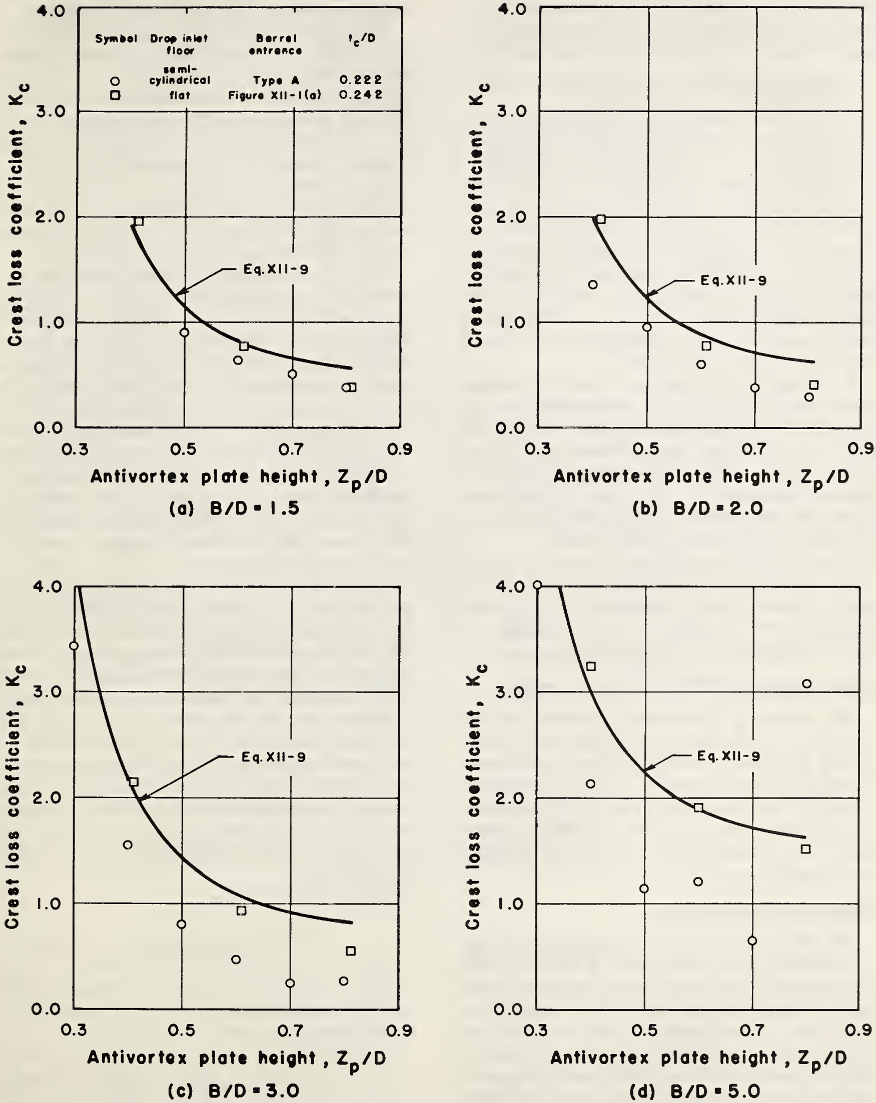


Figure XVII-4.—Effect of antivortex plate height on the crest loss coefficient for the type A entrance.

The test results presented in figures XVII-3 and XVII-4 show that the crest loss coefficients for the two-way drop inlet with a semicylindrical bottom can be computed from equation XII-9.

Barrel Entrance Loss Coefficients

The barrel entrance loss coefficient $\mathbf{K_t}$ multiplied by the velocity head in the barrel $\mathbf{h_{vp}}$ gives the energy loss between the midheight of the drop inlet and the barrel entrance plus the loss attributable to the barrel entrance. For the type A entrance, $\mathbf{K_t}$ also includes the losses caused by the elbow. The barrel entrance loss coefficient depends on the location of the drop inlet midheight piezometer, the drop inlet length **B/D**, the barrel slope **S**, and the type of barrel entrance, and is independent of conditions near the drop inlet crest.

A comparison of the test results obtained from the studies of two-way drop inlets with flat and with semicylindrical bottoms indicates that the barrel entrance loss coefficient is independent of the spillway discharge. Therefore, average values of $\mathbf{K_{t,1}}$, $\mathbf{K_{t,2}}$, and $\mathbf{K_t}$ were computed for each series. These average values are presented in tables XVII-2 and XVII-3.

The effect of the midheight piezometer location, drop inlet length, and barrel slope on the barrel entrance loss coefficient is presented. Equations for computing the $\mathbf{K_t}$ values are developed and their precision is discussed.

Effect of Midheight Piezometer Location

The effect of piezometer location on the crest loss coefficient and the method for computing the crest coefficient for a piezometer located 1**D** upstream from the drop inlet downstream endwall have been described in the section "Crest Loss Coefficients, Effect of Midheight Piezometer Location." Similar methods were used to compute $\mathbf{K_t}$.

Effect of Drop Inlet Length

The effect of the drop inlet length on the barrel entrance loss coefficient $\mathbf{K_t}$ is shown in figure XVII-5. The data plotted are for a barrel slope of zero, except that for the type A entrance the barrel slope downstream from the elbow is 20 percent. (The different values of the crest thickness $\mathbf{t_c/D}$ and of the antivortex plate height $\mathbf{Z_p/D}$ for the data plotted in figure XVII-5 have no effect on the barrel entrance loss coefficient.) The data presented in figure XVII-5 show that the barrel entrance loss coefficient decreases as the drop inlet length increases.

Compared in figure XVII-5 are the barrel entrance loss coefficients for four types of barrel entrances: (1) drop inlets with horizontal, semicylindrical bottoms and type A entrances (circular data points); (2) drop inlets with sloping, semicylindrical bottoms and type B entrances (square data points); (3) drop inlets with horizontal, flat bottoms and figure XII-1(a) entrances (triangular data points); and (4) drop inlets with horizontal, flat bottoms and figure XII-1(b) entrances (hexagonal data points).

The data presented in figure XVII-5 for zero barrel slope indicate that the barrel entrance loss coefficients $\mathbf{K_t}$ for two-way drop inlets with semicylindrical bottoms (square data points) and with flat bottoms (triangular and hexagonal data points) have the same value within the limits of precision of the experiments. This is a surprising result, because it would be expected that the square barrel entrance edges below the midheight of the flat bottom drop inlet barrel entrance, which do not exist in the semicylindrical bottom inlet, would cause disturbances that would be reflected in higher barrel entrance loss coefficients.

Because $\mathbf{K_t}$ is the same for the flat bottom and the type B entrances, this suggests that the first and second terms in equations XII-11 and XII-12, $0.43 + 0.55/(\mathbf{B/D})^{5/3}$, can represent the $\mathbf{K_t}$ values for drop inlets having semicylindrical bottoms when the barrel is on a zero slope. Therefore, these two terms plus a third term required because of the elbow downstream of the type A entrance and the sloping semicylindrical bottom of the type B entrance were used in developing equations to represent the barrel entrance loss coefficient for the two-way drop inlet with a semicylindrical bottom. These equations are:

for the type A entrance

$$K_t = 0.43 + \frac{0.55}{(B/D)^{5/3}} + K_{el} \qquad \text{(XVII-1)}$$

where the elbow loss coefficient $\mathbf{K_{el}}$ is 0.10 for an 11.5-degree elbow, and

for the type B entrance

$$K_t = 0.43 + \frac{0.55}{(B/D)^{5/3}} - \frac{0.75}{B/D}S \qquad \text{(XVII-2)}$$

Equations XVII-1 and XVII-2 become identical for a zero barrel slope, since for this condition

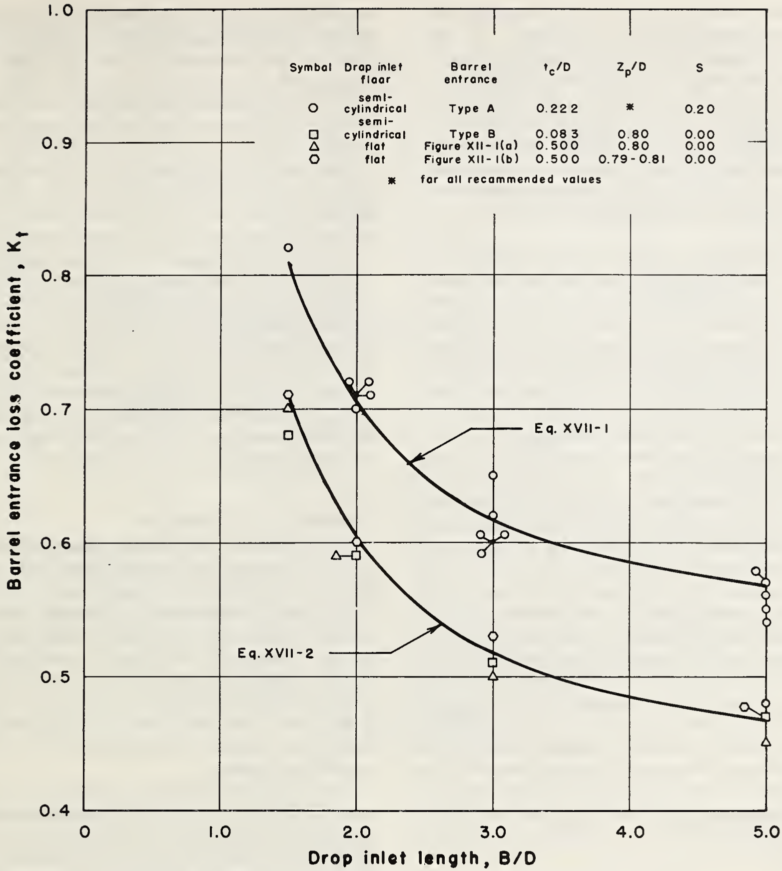


Figure XVII-5.—Effect of drop inlet length on the barrel entrance loss coefficient.

$K_{el} = 0$ in equation XVII-1 and $S = 0$ in equation XVII-2.

Comparisons of the data with the curves presented in figure XVII-5 show that the barrel entrance loss coefficients computed from equations XVII-1 and XVII-2 agree well with the data for type A and type B entrances. The precision with which equations XVII-1 and XVII-2 represent the data is presented later in the text.

Effect of Elbow

The barrel entrance loss coefficients for the type A entrance are higher than those for the type B entrance. Because the type A and type B entrances are otherwise identical when the barrel slope for the type B entrance is zero, these higher values are attributed to the presence of the elbow downstream from the type A barrel entrance. Therefore, the differences between

the barrel entrance loss coefficients for the type A entrance (column heading: K_t, Observed in table XVII-2) and the type B entrance (column heading: K_t, Observed in table XVII-3) must represent the elbow loss coefficients K_{el}. The average elbow loss coefficient determined from 16 valid series for the 5**D**-, 3**D**-, 2**D**-, and 1.5**D**-long drop inlets is $K_{el} = 0.10$. The elbow loss coefficient multiplied by the velocity head in the barrel gives the energy loss due to the elbow.

This separation of the elbow loss from the barrel entrance loss makes possible the use of the type A entrance with barrel slopes other than the barrel slope used for the reported tests. However, because no tests were made using barrel slopes other than 20 percent (miter elbow deflection of 11.5 degrees), recourse must be had to other sources to obtain the elbow loss for other deflection angles.

The elbow loss coefficient reported by Anderson[5] is about 0.03 for an 11.5-degree miter elbow. This is significantly less than the 0.10 measured for the type A entrance. A reason for this difference may be that the distance between the barrel entrance and the elbow influences the flow approaching the elbow. A distance of about 20**D** is usually required before the disturbances caused by the barrel entrance disappear and the velocity distribution within the barrel assumes its normal pattern. Therefore, when the elbow is located less than about 20**D** from the barrel entrance, the disturbances caused by the entrance likely increase the energy loss in the elbow. Because the elbow for the type A entrance is about 1.5**D** from the barrel entrance, the observed K_{el} value of 0.10—0.07 higher than those reported by Anderson—is not unexpected.

Effect of Barrel Slope

The data for the type B entrance in figure XVII-6 show that the barrel entrance loss coefficient K_t decreases linearly as the barrel slope increases and that the influence of the barrel slope on K_t decreases as the drop inlet length increases (decreasing slope of the lines representing the data). To represent these effects, the third term of equation XVII-2 was developed from the test results for 1.5**D**-, 2**D**-, 3**D**-, and 5**D**-long drop inlets having semicylindrical bottoms. The agreement is good between the observed (open data points) and computed (solid line) results.

The data for the figure XII-1(b) entrance (figure XVII-6 data points with a slash), the data for the figure XII-1(a) entrance (solid data points), and equation XII-12 (dash curve) have been added to figure XVII-6. This facilitates comparison of the results of the tests on the sloping, semicylindrical bottom drop inlet with the test results for the corresponding horizontal, flat bottom drop inlet. The slope effect for the sloping, semicylindrical bottom type B entrance is less than for the horizontal, flat bottom. However, the barrel entrance loss coefficients for these two bottom configurations do not differ greatly.

Precision of the Equations

The precision with which equations XVII-1 and XVII-2 represent the data was determined by computing the percentage deviations of the computed K_t values from the observed values of K_t. The barrel entrance loss coefficients observed, computed, and their percentage differences are presented in table XVII-2 for the type A entrance and in table XVII-3 for the type B entrance. The data used for this precision analyis are for drop inlets which meet the recommended criteria.

The average error between the computed and observed values for the type A entrance based on the 16 valid tests identified by note a in table XVII-2 for which data are available is +1.9 percent. The errors range from +18.8 percent (series W-533) to −4.6 percent (series W-521).

The average error between the computed and observed values for the type B entrance based on the 24 tests listed in table XVII-3 is +0.9 percent. The errors range from +5.0 percent (series A-1510) to −7.3 percent (series A-1495).

Entrance Loss Coefficients

The entrance loss coefficient K_e multiplied by the velocity head in the barrel gives the total energy loss attributable to the drop inlet and the barrel entrance. The total entrance energy

[5] Anderson, A. G. Hydraulics of conduit bends. University of Minnesota, St. Anthony Falls Hydraulic Laboratory, Bull. No. 1, 22 pp., illus., December 1948, figure 5.

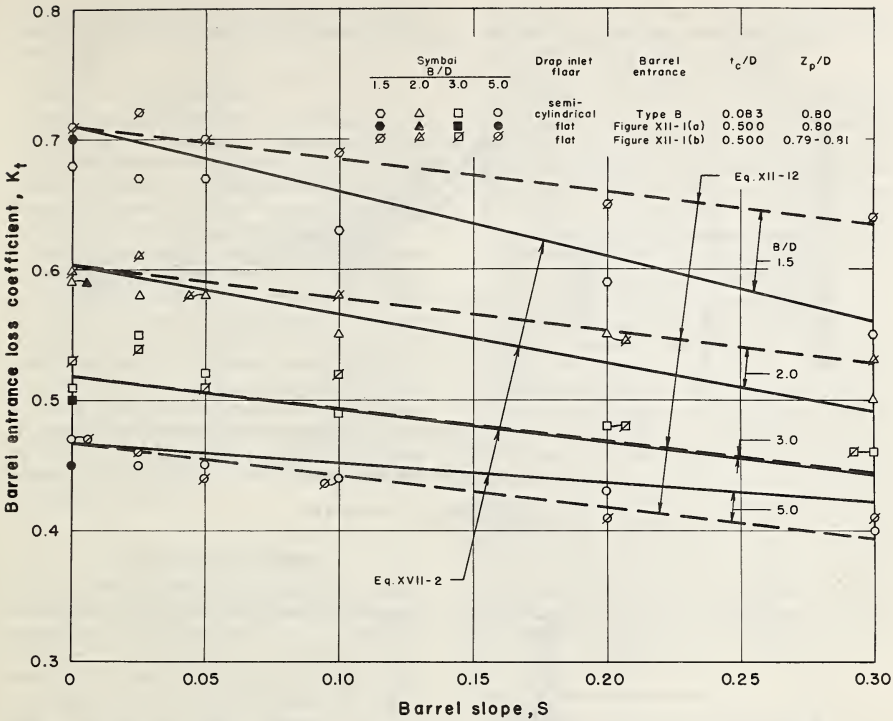


Figure XVII-6.—Effect of barrel slope on the barrel entrance loss coefficient for the type B entrance.

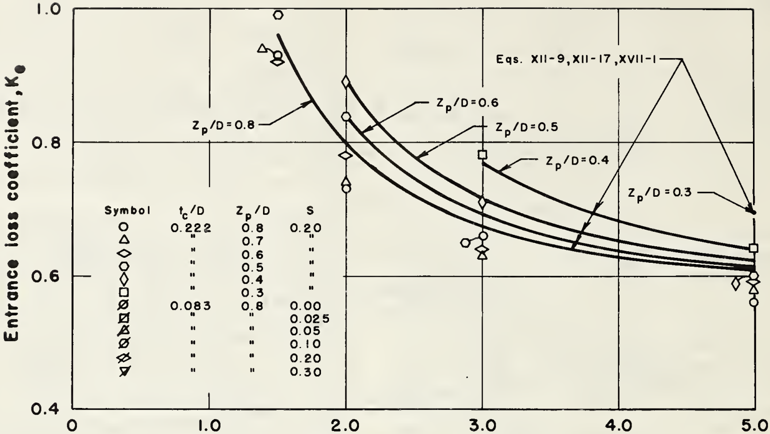
loss is the sum of the energy losses that occur near the crest and in the vicinity of the barrel entrance. Therefore, except for the location of the midheight piezometer in the drop inlet, all the variables that affect either K_c or K_t also affect K_e. As a result, the entrance loss coefficient depends on the crest thickness t_c/D, the antivortex plate height Z_p/D, the drop inlet length **B/D**, the barrel slope **S**, and the type of barrel entrance. The effects of these variables on the entrance loss coefficient are the same as their combined effects on K_c and K_t. The experimental results and equations for computing K_e are presented in the following paragraphs.

Equation XII-17 is a general equation that gives the entrance loss coefficients for two-way drop inlets in terms of K_c and K_t. This equation is:

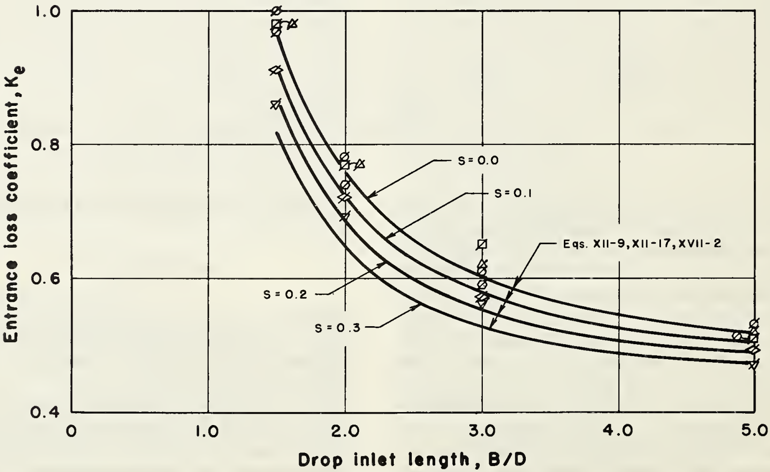
$$K_e = K_c\left(\frac{\pi}{4\ B/D}\right)^2 + K_t \qquad \text{(XII-17)}$$

where K_c is computed from equation XII-9, and K_t is computed from equation XVII-1 for the type A barrel entrance and from equation XVII-2 for the type B barrel entrance.

The observed and computed entrance loss coefficients for drop inlets with the type A barrel entrance are presented in table XVII-2 and figure XVII-7(a), and for drop inlets with the type B barrel entrance in table XVII-3 and figure XVII-7(b). Also figure XVII-7 shows a comparison of the experimental test results with the curves



(a) Type A entrance



(b) Type B entrance

Figure XVII-7.—Effect of drop inlet length on the entrance loss entrance coefficient. $Z_1/D = 5.0$.

representing equations XII-9, XVII-1 and XVII-2, and XII-17. The agreement is considered to be satisfactory.

Precision of the Equations

The precision of equation XII-17 depends on the precision of equations XII-9 and XVII-1 or XVII-2. The entrance loss coefficients observed, computed, and their percentage differences are presented in table XVII-2 for the type A entrance and in table XVII-3 for the type B entrance.

The average error between the computed and observed values for the type A entrance based on the 16 tests identified by note a in table XVII-2 for which data are available is +6.6 percent. The errors range from +9.6 percent (series W-522) to +1.5 percent (series W-521).

The average error between the computed and observed values for the type B entrance based on 24 valid tests listed in table XVII-3 is −3.3 percent. The errors range from 0.0 percent (series A-1494, A-1506 and A-1510) to −9.2 percent (series A-1495).

Pressure Coefficients

The full-flow barrel entrance pressures were measured on the crown and invert **D**/2 from the barrel entrance for both the type A and type B entrances. For the type A entrance, the pressure on the invert of the elbow was also measured about **D**/8 downstream from the elbow miter. These measured pressures are expressed in terms of pressure coefficients defined as the ratio of the deviation of the measured pressures from the friction gradeline $\mathbf{h_n}$ to the velocity head in the barrel $\mathbf{h_{vp}}$. Details for computing the friction gradeline and the pressure coefficients are given in Part I.

The drop inlets tested are listed in table XVII-1. Because the crest thickness and antivortex plate height do not affect the barrel pressure coefficients, these variables do not enter into the barrel pressure coefficient analysis.

Test results from the studies of the two-way drop inlets with semicylindrical bottoms and with flat bottoms indicate that the full-flow pressure coefficients in the barrel do not vary with the spillway discharge. Therefore, the pressure coefficients obtained from several test runs each with a different discharge were averaged for each test series. These average pressure coefficients are listed in tables XVII-2 and XVII-3 in the columns headed $\mathbf{h_n/h_{vp}}$ and are used for the subsequent analyses.

Figure XVII-8 shows the pressure coefficient data at three locations for the type A entrance: on the crown (open data points) and on the invert (solid data points) **D**/2 downstream from the barrel entrance, and on the invert about **D**/8 downstream from the elbow miter (data points with a slash). These data are for antivortex plate heights that meet the recommended criteria. The clusters of the data confirm that the antivortex plate height does not affect the pressure coefficient in the barrel near its entrance.

The data plotted in figure XVII-8 show that for the type A entrance the pressure coefficients on the crown are lower than those on the invert. The data presented in table XVII-3 for the type B entrance and in table XII-1 and figures XII-25, XII-26, and XII-27 for the figure XII-1 entrances also agree with this finding. Most crown pressure coefficients shown in figure XVII-8 are about 1.1 barrel velocity heads below the friction gradeline. Because the lowest pressures determine the potential for cavitation, the pressure coefficients on the crown **D**/2 from the entrance are analyzed to evaluate the effect on them of the drop inlet length and the barrel slope. There will be no further analysis of the invert pressure coefficients.

Effect of Drop Inlet Length

The effect of the drop inlet length on the pressure coefficient $\mathbf{h_n/h_{vp}}$ is shown in figure XVII-9. The data indicate that the pressure coefficient increases as the drop inlet length increases until it becomes constant for lengths longer than about 3**D**.

Figure XVII-9 shows a comparison of the pressure coefficients for four types of barrel entrances: (1) drop inlets with horizontal, semicylindrical bottoms and type A entrances (square data points); (2) drop inlets with sloping, semicylindrical bottoms and type B entrances (circular data points); (3) drop inlets with horizontal, flat bottoms and figure XII-1(a) entrances (triangular data points); and (4) drop inlets with horizontal, flat bottoms and figure XII-1(b) entrances (hexagonal data points). The barrel slopes used for the comparison are 20 percent for the type A entrance and zero for the remaining three entrances. Because the type A entrance has a horizontal bottom and the barrel

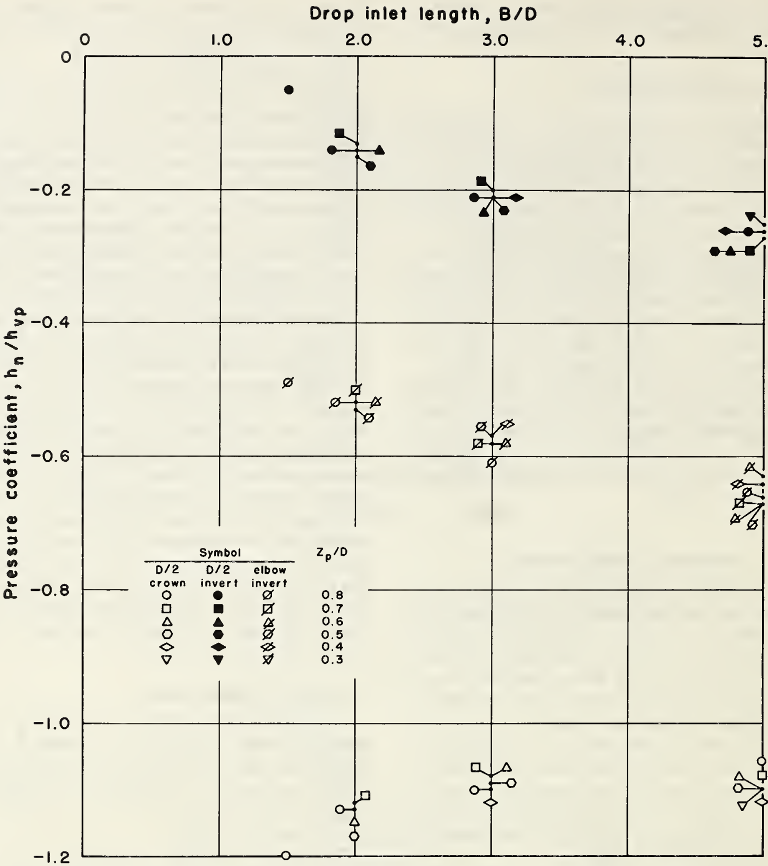


Figure XVII-8.—Pressure coefficients in the barrel entrance for the type A entrance.

slope upstream of the elbow is zero, the barrel slope is considered to be zero for this comparison. And, because the crest thickness does not affect the pressure in the barrel, the use of data for different crest thicknesses to compare the four entrances is permissible.

The data shown in figure XVII-9 indicate that the pressure coefficients for the type A entrance (square data points) are about 0.14 barrel velocity heads higher than those for the type B entrance (circular data points). The reason for these higher pressure coefficients is that the elbow in the type A entrance causes higher pressures on the crown of the barrel. The data also show that the trends of the pressure coefficients with drop inlet length for the four entrances are the same.

Because the type A entrance is similar to the figure XII-1(b) entrance except for the shape of the drop inlet bottom, the form of equation XII-34, which represents the crown pressure coefficients for the figure XII-1(b) entrance, was

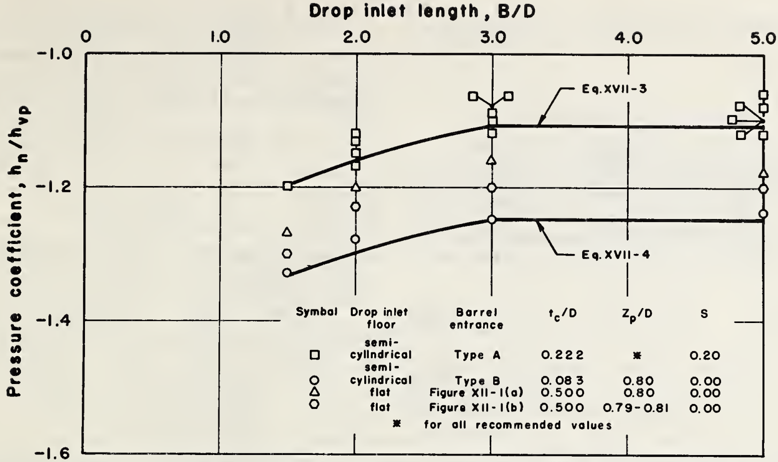


Figure XVII-9.—Effect of drop inlet length on the crown pressure coefficient **D**/2 downstream from the barrel entrance.

used with the data for two-way drop inlets with semicylindrical bottoms to develop the equations for computing the crown pressure coefficients for the type A and type B entrances. These equations are:
for the type A entrance,

$$\frac{h_n}{h_{vp}} = -1.25 + 0.3 \log_{10} \frac{B}{D} \qquad \text{(XVII-3)}$$

for $1.5 \leqq B/D \geqq 3.0$. (When $B/D > 3.0$, use $B/D = 3.0$.) and for the type B entrance,

$$\frac{h_n}{h_{vp}} = -1.39 + 0.3 \log_{10} \frac{B}{D} + 0.15\,S \qquad \text{(XVII-4)}$$

for $1.5 \leqq B/D \leqq 3.0$. (When $B/D > 3.0$, use $B/D = 3.0$.) The slope term in equation XVII-4 is discussed in the following section.)

In figure XVII-9 the agreement is good between the data and the pressure coefficients computed from equations XVII-3 and XVII-4. The precision of these equations is discussed later in the text.

Effect of Barrel Slope

Data on the effect of the barrel slope on the pressure coefficient are available only for the type B entrance.

The effect of the barrel slope on the pressure coefficient is shown in figure XVII-10 for the type B entrance. The data presented in figure XVII-10 and the third term in equation XVII-4 indicate that the pressure coefficient increases slightly as the barrel slope increases.

Figure XVII-10 shows a comparison of the data for two-way drop inlets with semicylindrical bottoms and with flat bottoms. This comparison indicates that the effect of the barrel slope on the pressure coefficient is greater for drop inlets with flat bottoms (data points with a slash and solid points) than for those with semicylindrical bottoms (open data points). A similar conclusion is obtained by comparing the coefficients of the third term in equation XII-33 ($+0.55\,S$), XII-34 ($+S/3$), and XVII-4 ($+0.15\,S$). The agreement is good between the observed and computed results shown in figure XVII-10.

Precision of the Equations

The precision with which equations XVII-3 and XVII-4 represent the data was determined by comparing the computed and observed values of h_n/h_{vp}. The data used for this precision analysis are for drop inlets that meet the recommended criteria.

The average error between the computed (equation XVII-3) and observed values for the type A entrance based on 16 valid tests listed in table XVII-2 is -0.02 barrel velocity heads. The

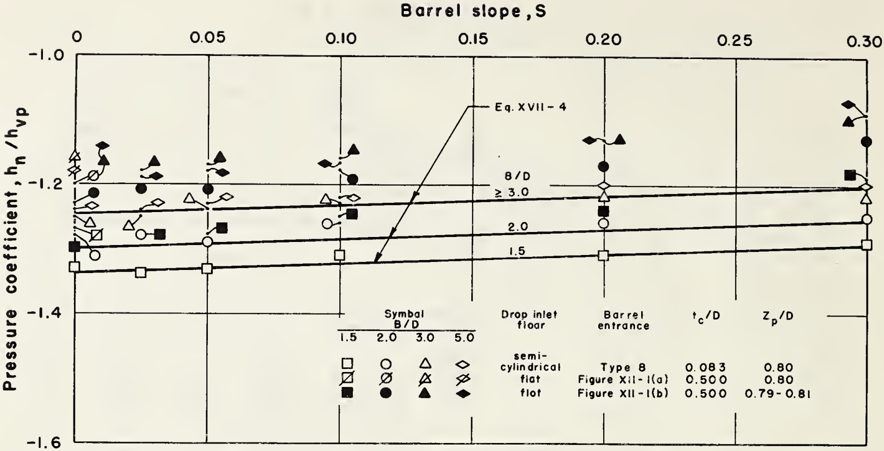


Figure XVII-10.—Effect of barrel slope on the crown pressure coefficient D/2 downstream from the type B entrance.

differences between the computed and observed values range from +0.01 to −0.05 barrel velocity heads.

The average error between the computed and observed values for the type B entrance based on the 24 tests listed in table XVII-3 is zero, which illustrates the excellent precision of equation XVII-4. The differences between the computed and observed values range from +0.02 to −0.02 barrel velocity heads.

Recommendations

Drop Inlet Dimensions

The drop inlet dimensions that will assure satisfactory performance of the two-way drop inlet with a horizontal, semicylindrical bottom and the type A barrel entrance shown in figure XVII-1(a) are:

height: $Z_1 \geqq 3D$
length: $B \geqq 1.5D$
antivortex plate height:
$Z_p = 0.8D$, $0.5D$, $0.4D$, and $0.3D$
for 1.5D-, 2.0D-, 3.0D-, and 5.0D-long drop inlets.

The minimum drop inlet dimensions recommended for the two-way drop inlet with a horizontal, semicylindrical bottom agree well with the minimum dimensions recommended for the two-way drop inlet with a flat bottom. Therefore, the drop inlet proportions presented in figure XII-28 can be used for designing two-way drop inlets with horizontal, semicylindrical bottoms.

No performance tests were made on the type B entrance shown in figure XVII-1(b), so no data are available on which to base recommendations for the dimensions of drop inlets having sloping, semicylindrical bottoms. Information available when this report was written suggests that model tests should be made to determine the performance characteristics of this type of entrance if its use is contemplated.

Crest Loss Coefficient

The equation

$$K_c = \left\langle 1 - 2\frac{t_c}{D} \right\rangle^2 + \frac{0.1}{(Z_p/D)^3} + 0.02\left(\frac{B}{D}\right)^{5/2} \qquad \text{(XII-9)}$$

can be used to compute the crest loss coefficients for two-way drop inlets with semicylindrical bottoms. The term in pointed brackets is zero for negative values, that is, the term is positive for $t_c/D < 0.5$ and zero for $t_c/D \geqq 0.5$.

Barrel Entrance Loss Coefficient

Equations XVII-1 and XVII-2 can be used to compute the barrel entrance loss coefficients K_t for two-way drop inlets with semicylindrical bottoms. They are:
for the horizontal, semicylindrical bottom (type A) entrance,

$$K_t = 0.43 + \frac{0.55}{(B/D)^{5/3}} + K_{el} \qquad \text{(XVII-1)}$$

where the elbow loss coefficient K_{el} depends on the elbow angle and the location of the elbow in the barrel (for an 11.5-degree miter elbow $K_{el} = 0.1$) and
for the sloping, semicylindrical bottom (type B) entrance,

$$K_t = 0.43 + \frac{0.55}{(B/D)^{5/3}} - \frac{0.75}{B/D} S \qquad \text{(XVII-2)}$$

Entrance Loss Coefficient

The equation

$$K_e = K_c \left(\frac{\pi}{4\ B/D}\right)^2 + K_t \qquad \text{(XII-17)}$$

can be used to compute the total entrance loss coefficient K_e.

Pressure Coefficients

Equations XVII-3 and XVII-4 can be used to compute the pressure coefficients h_n/h_{vp} on the barrel crown $D/2$ downstream from the barrel entrance:
for the horizontal, semicylindrical bottom (type A) entrance,

$$\frac{h_n}{h_{vp}} = -1.25 + 0.3 \log_{10} \frac{B}{D} \qquad \text{(XVII-3)}$$

for $1.5 \leqq B/D \leqq 3.0$. (When $B/D > 3.0$, use $B/D = 3.0$.) and
for the sloping, semicylindrical bottom (type B) entrance,

$$\frac{h_n}{h_{vp}} = -1.39 + 0.3 \log_{10} \frac{B}{D} + 0.15\ S \qquad \text{(XVII-4)}$$

for $1.5 \leqq B/D \leqq 3.0$. (When $B/D > 3.0$, use $B/D = 3.0$.)

Nomenclature

B Drop inlet length

C Weir coefficient in the equation $Q = CLH^{3/2}$, in ft/s units

D Barrel inside diameter

g Gravitational acceleration

h_n Local pressure head deviation from the friction gradeline in the barrel

h_{vp} Velocity head in the barrel $= V_p^2/2g$

h_{vr} Velocity head in the drop inlet $= V_r^2/2g$

H Head over weir crest, feet

K_c Crest loss coefficient; for the type B entrance it is computed from $K_{c,1}$ and $K_{c,2}$ (See footnote 4 of table XVII-3.)

$K_{c,1}$ Crest loss coefficient computed from the readings of the piezometer located at the midheight of the drop inlet and $B/3$ upstream from the downstream endwall

$K_{c,2}$ Crest loss coefficient computed from the readings of the piezometer located at the midheight of the drop inlet and $D/2$ upstream from the downstream endwall

K_e Entrance loss coefficient

K_{el} Elbow loss coefficient

K_t Barrel entrance loss coefficient; for the type B entrance it is computed from $K_{t,1}$ and $K_{t,2}$ (See footnote 4 in table XVII-3.)

$K_{t,1}$ Barrel entrance loss coefficient computed from the readings of the piezometer located at the midheight of the drop inlet and $B/3$ upstream from the downstream endwall

$K_{t,2}$ Barrel entrance loss coefficient computed from the readings of the piezometer located at the midheight of the drop inlet and $D/2$ upstream from the downstream endwall

L Length of weir crest, feet

L_o Antivortex plate overhang

Q Discharge, cubic feet per second

S Barrel slope, sine

t_c Drop inlet crest wall thickness

V_p Velocity in the barrel

V_r Velocity in the drop inlet

W Drop inlet width

Z_1 Drop inlet height, crest to drop inlet floor at the barrel entrance

Z_p Height of antivortex plate above the drop inlet crest

$\langle\,\rangle$ The quantity in the pointed brackets is zero for negative numbers.

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